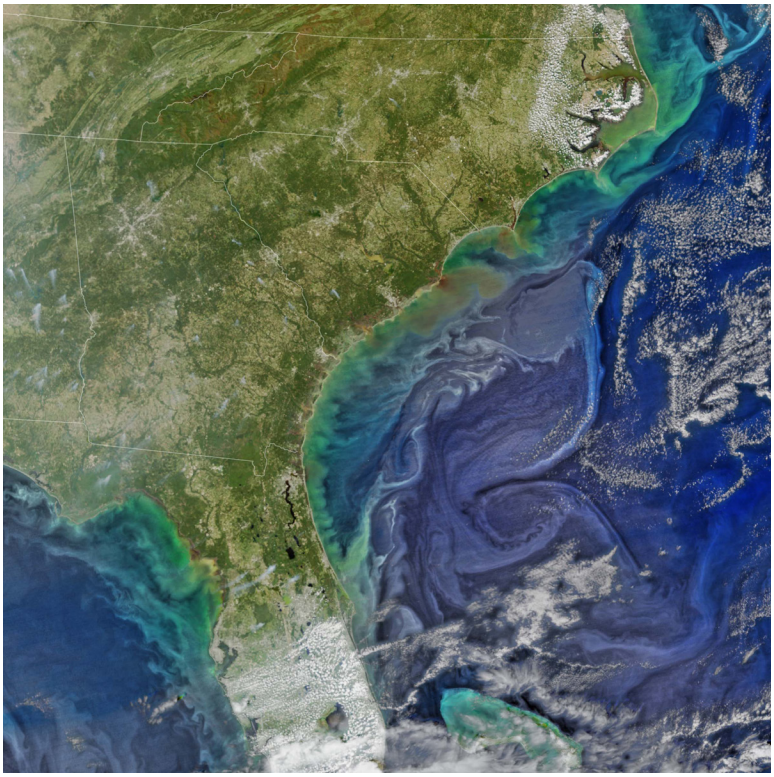


2 DELIVERING ON THE 2012-2021 STRATEGIC PLAN

DELIVERING ON THE 2012-2021 STRATEGIC PLAN

The complex nature and rapid pace of global change require adaptive management and science-based response strategies. Fundamental but applications-oriented research can provide the knowledge that governments, businesses, and communities need as they address global changes that pose growing risks to life, infrastructure, ecosystems and natural resources, and the economy.

The 2012–2021 Strategic Plan defined four goals for USGCRP: advance science, inform decisions, conduct sustained assessments, and communicate and educate *(Figure 2: The U.S. Global Change Research Program at a Glance).* The first of these goals guides continued advances in core Program capabilities—Earth-system understanding, integrative modeling, Earth observations, and accessible and actionable science—and provides the scientific foundation for the other three goals. Feedback from decision support, assessment, and engagement processes in turn shapes the development of future research priorities. The Strategic Plan guides the development of these capabilities and goals, and provides the flexibility for annual prioritization of particular research areas in response to new challenges *(A Look Ahead at FY 2017)*.

Advancing Science

USGCRP agency and interagency research advances understanding of the interacting physical, chemical, biological, and societal components of the Earth system; how they are impacted by climate and other global changes; and the ways in which science can inform responses to change. Capabilities in observing and modeling Earth-system processes allow measurement of the natural and human-induced changes affecting the Earth system and enable a deepening understanding of how future changes may evolve.

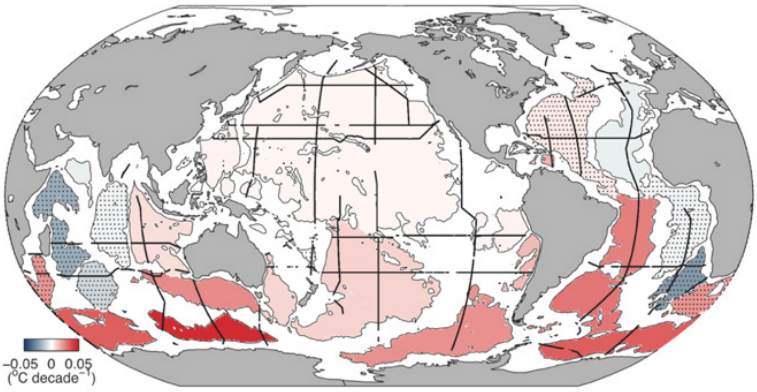
USGCRP's member agencies maintain long-term investments in multidisciplinary satellite, airborne, ground-based, and ocean-based observing systems. Information from these systems creates a record of change in Earth-system processes over time that advances understanding of their drivers and potential future behavior *(Appendix III. Observations to Support Global-Change Research)*. Both sustained and experimental observations provide critical information for understanding the Earth's climate system, how it interacts with other Earth-system processes, and the impacts on society *(Highlights 1-3)*.

Observational investments have helped reveal trends in atmospheric greenhouse gas levels over time. These measurements facilitate large-scale analysis of how greenhouse gas emissions levels from natural and human sources are being impacted by policy choices, how ecosystems respond to climate warming and other changes, and how natural emissions sources may evolve in the future. Under the Paris Agreement, adopted in December 2015 by the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change, 195 countries committed to nationally determined greenhouse gas emissions targets and regular reporting, with a U.S. target of a 26–28% reduction in emissions relative to 2005 levels by 2025. As the Paris Agreement is implemented, capacity for ongoing estimates of human emissions and monitoring of

natural sources, and assessment of the emissions-reduction potential of mitigation activities, is particularly relevant. Current USGCRP efforts include tracking how carbon-rich ecosystems respond to climate warming by measuring emissions of methane and carbon dioxide as soils warm and the resulting effects on the climate *(Highlight 4)*. Individual and multiagency observing systems also allow emissions monitoring for major urban areas *(Highlight 5)*, and calculation of the carbon and methane budgets for the entire globe *(Highlight 6)*.

In addition to their direct use in science and decision support, Earth observations are used to develop and test models of the Earth system and its changing dynamics. These models provide information about possible futures on different timescales, including longer-term projections of climate conditions under different global emissions scenarios *(Highlight 7)*, shorter-term predictions of climate conditions over an upcoming growing season *(Highlight 8)*, and the response of ecosystems to warming over decades to centuries.

Highlight 1. Measuring Change at Sea



Multi-decadal ship-based surveys show that the ocean is taking up most of Earth's excess anthropogenic heat, with the deep ocean warming as well as the surface layers. The figure shows average warming rates (°C per decade) below 4,000 meters (color bar) estimated for deep ocean basins (thin gray outlines), centered on 1992–2005. Stippling indicates that warming rates in a given area are not significantly different from zero at 95% confidence—i.e., it is very unlikely that significant warming or cooling occurred in that basin over 1992-2005. The positions of the repeat surveys from which these warming rates are estimated are also shown (thick black lines) (Source: Talley et al, 2016, using data from Purkey and Johnson 2010[12]).

The oceans have absorbed almost all of the excess heat generated by increasing atmospheric greenhouse gas concentrations and a large fraction of anthropogenic carbon dioxide, with profound implications for ecosystems and the climate system[10]. Ship-based hydrographic surveys are the only current means for simultaneously measuring physical, biological, and biogeochemical properties of the global oceans from the surface to the seafloor and are a crucial resource for understanding ocean change and its role in the climate system. Building on global hydrographic surveys underway since the 1970s, the Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP)—an international effort established in 2007 and funded by NSF and NOAA in the United States—samples selected hydrographic sections each decade. In combination with efforts from previous decades, data emerging from GO-SHIP reveals profound warming in deep ocean waters around the globe. In a warming climate, the global ocean is a major reservoir for excess heat and carbon dioxide generated by human activities—both vital components in understanding how much and how quickly the atmosphere will warm. New data show that the oceans have taken up the majority of anthropogenic heat in the Earth system in recent decades, with approximately 19% of this heat found below 2,000 meters, and the most intense warming in the Southern Ocean. The ocean is also acting as a major carbon sink: from 1994–2010, approximately 27% of carbon released by the burning of fossil fuels and land-use change was taken up by the oceans, acidifying the upper layers[11].

GO-SHIP builds on two decades of research under the World Ocean Circulation Experiment (WOCE) and the CLImate VARiability and Predictability (CLIVAR) programs and is a component of the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS). Together, these efforts have led to major scientific advances in understanding of the roles of the ocean in climate change, carbon cycling, and biogeochemical responses to climate change. These findings demonstrate the value of continuous time-series measurements and their ability to provide insights into why and how critical Earth systems are changing over time.

Highlight 2. Connecting the Remote Ocean to Global Climate

Atmospheric composition and circulation over the tropical western Pacific Ocean play important roles in the Earth's climate system. In this remote region, rising air heated by some of the warmest seawater in the world moves gases produced by ocean organisms and other chemicals to higher altitudes, where water vapor and ozone exert their strongest influence on the climate. As the climate warms, the intensity of this transport mechanism will increase and may contribute to large-scale changes in atmospheric composition. Details of these dynamics, including how they vary over time and space, are needed to accurately model the distribution of water vapor and ozone at high altitudes and to predict their impacts on climate. To address gaps in knowledge about these dynamics, an intensive field study using three research aircraft was conducted jointly by scientists from the United States and the United Kingdom, affiliated with the NSF-funded National Center for Atmospheric Research, NASA, NOAA, and several U.S. and European universities.

Analyses show that in addition to the role of local transport mechanisms, large-scale circulations also alter atmospheric composition over the Pacific, creating distinct structures in ozone and water vapor[13]. Measurements also show that air over the remote, tropical-Pacific Ocean often contains significant amounts of pollutants associated with slash-and-burn agriculture in Asia and Africa[14]. In addition, rising-air movement in the region was observed to transport chemicals produced by biological processes in the ocean to the upper atmosphere, where they contribute to ozone destruction[15].

These findings provide important new insight into how the remote, tropical-Pacific atmosphere interacts with and influences the distribution of ozone, water vapor, and other particles in the upper atmosphere. Follow-on research will examine how improved understanding of these transport processes can improve the ability to model upper-atmospheric composition and regional- and global-climate forcings.

Highlight 3. Studying Thunderstorms by Night

Over the Great Plains region of the United States, summertime thunderstorms often occur after sunset. Much of this nighttime rainfall is caused by large, organized storm systems and plays a critical role in the hydrology and agriculture of the region, especially over the more arid western Great

A Plains Elevated Convection at Night (PECAN) mobile observing station. The PECAN campaign focused on characterizing conditions that lead to nighttime storm formulation over the Great Plains, in order to improve the ability of climate models to make long-term projections about precipitation and hydrology. (Source: James Kurdzo).

Plains. During the summer months, these nighttime storm systems provide 30–70% of the region's precipitation and can also cause severe weather, including flash floods, intense damaging winds, and large hail. Current weather and climate models have difficulty predicting the onset, location, frequency, and intensity of these nighttime cloud systems. While understanding these systems is important for improved weather forecasts and predictability of extreme events, it is also critical for improving long-term, climate-model projections of shifts in precipitation and hydrology. The multiagency Plains Elevated Convection at Night (PECAN) field campaign was sponsored by NSF, in collaboration with NOAA, NASA, and DOE, to obtain targeted observations before and during nighttime severe storms in order to learn how they form, why some become severe, and how to better predict their characteristics in weather and climate models.

The PECAN experiment took place June–July 2015, extending over most of western and central Kansas, northern Oklahoma, and southern Nebraska. A key focus was to better sample the atmospheric layer between 500–1000 meters above the ground, where rising-air motion related to rainfall initiates. The datasets collected during PECAN will help scientists characterize the conditions that lead to individual storm formation, as well as their organization into large-scale systems that can result in significant precipitation. The results will also have relevance beyond the Great Plains, as organized nighttime thunderstorms are common in mid-latitude regions around the globe.

Highlight 4. Studying Northern-Ecosystem Response to a Changing Climate

Northern peatlands contain vast organic carbon stocks in danger of release into the atmosphere as greenhouse gases as the climate warms, leading to a positive-feedback cycle of further warming and carbon release. Through field experiments in a Minnesota peat bog, DOE's Oak Ridge National Laboratory, the USDA Forest Service (USDA-FS), and EPA are collaborating alongside university partners to test how peatland ecosystems respond to conditions that simulate the atmosphere of the future, and improve the ability to predict the release of stored carbon and its impact on climate warming. The Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE) experiment is measuring changes in peatland biogeochemical cycles over ten years in the USDA-FS's Marcell Experimental Forest, using a DOE-designed facility for exposing forest plots to elevated temperatures and carbon dioxide levels and offering a look at below-ground activity where most of the ecosystem's carbon is stored.

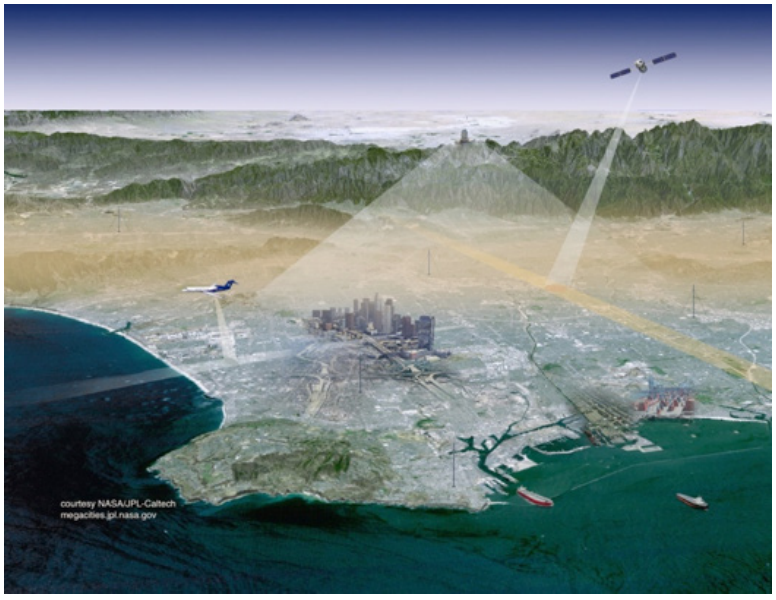
An aerial view of the SPRUCE site showing open-top chambers where experimentally-elevated atmospheric-carbon-dioxide concentrations and temperatures simulate future climatic conditions in a carbon-rich northern-peat bog. (Source: Oak Ridge National Laboratory).

DOE scientists are focused on how 10,000 years of accumulated carbon stored in the ecosystem responds to warming, particularly how likely it is for accumulated carbon to be released into the atmosphere as carbon dioxide and methane. USDA-FS scientists and colleagues are leading efforts to understand the effects of warming on wetland hy-

drology and the cycling of mercury, while EPA researchers are developing models to better understand how warming affects decomposition processes in the ecosystem. Results will help reveal the mechanics of peatland response to climate change, how quickly carbon might be released, and what that means for the ecosystem and for future climate change.

Highlight 5. Monitoring Urban Emissions Hotspots

As of 2010, urban areas are home to more than half of the world's population, produce at least 70% of carbon-dioxide emissions from fossil fuels, and emit a significant amount of anthropogenic methane, but represent a small fraction of the Earth's land surface. Currently, greenhouse gas emissions estimates for many cities are either unavailable or are generated using self-reported data from particular sectors, and contain significant uncertainties. Although methods for comprehensive measurement of urban emissions have been tested in smaller cities with stable emissions, these techniques have not yet been extended to the more complex environments in growing megacities, and ultimately, to a global urban- monitoring system that can establish baseline-emissions estimates for large cities and help assess the efficacy of mitigation policies over time. To address this gap, the Megacities Carbon Project is developing and testing methods for measuring emissions trends of carbon dioxide, methane, and carbon monoxide from an individual megacity and in selected major sectors, beginning with pilot activities in Los Angeles.



As part of the Megacities Carbon Project, sensors located around the Los Angeles basin provide continuous ground-based measurements of the atmospheric concentrations of carbon dioxide, methane, and carbon monoxide. Remote-sensing instruments on Mt. Wilson and at Caltech provide measurements throughout the height of the atmosphere. Aircraft and mobile laboratories also provide infrequent but intensive measurements throughout the height of the atmosphere. (Source: NASA-Jet Propulsion Laboratory).

As part of this effort, a network of 14 surface-monitoring sites located within and around the Los Angeles basin provides continuous measurements of the atmospheric concentrations of carbon dioxide, methane, and carbon monoxide. Remote-sensing instruments provide emissions measurements from multiple sites.

Sustained measurement of atmospheric concentrations and emissions sources of greenhouse gases in urban areas, along with transparent data sharing, can help provide decision makers with the evidence base to evaluate emissions-mitigation policies and track how well policies are working over time. After pilot activities are established in several cities, the project may be expanded to include additional cities.

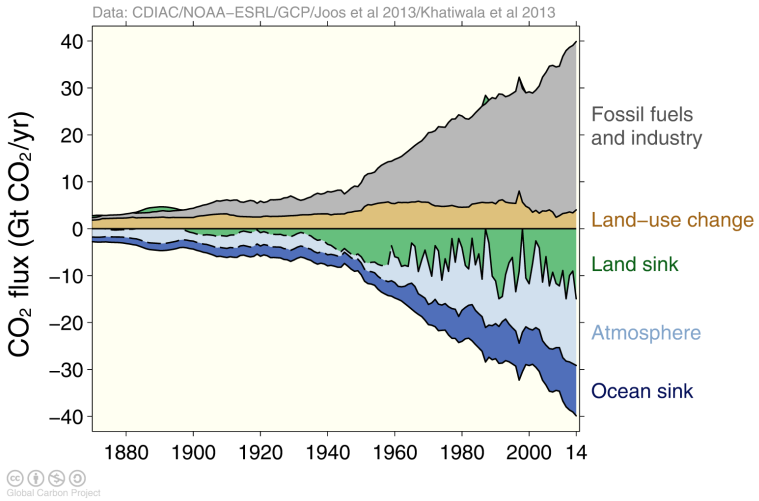
The Los Angeles component of the project is jointly funded by the U.S. National Institute of Standards and Technology, NASA, NOAA, and the Keck Institute for Space Studies. The California Air Resources Board and the University of California Discovery are also partners.

Highlight 6. Tracking Earth's Carbon and Methane Budgets

Founded in 2001, the Global Carbon Project (GCP) is an international scientific collaboration investigating the biophysical and human components of the global carbon cycle, the interactions between them, and their response to a changing climate. The GCP tracks sources and sinks of carbon dioxide and methane, the two most important greenhouse gases directly emitted by human activities—providing annual updates on emissions trends, atmospheric concentrations, and sources of uncertainty, in a format accessible to policymakers.

The GCP released its annual update of the Global Carbon Budget (GCB) in December 2015, analyzing emissions trends through 2014. It found that carbon dioxide emissions from fossil-fuel combustion and industrial activity increased by just 0.6% in 2014, in contrast with the rapid growth in emissions in previous years. 2015 emissions are expected to flatten or drop slightly, despite continued economic growth worldwide. Still, 2014 emissions were the highest in human history, and 60% higher than in 1990. Ocean and land carbon sinks removed, respectively, 27% and 37% of the total quantity of carbon dioxide emitted from fossil fuel use and land-use change in 2014.

Because methane has a shorter atmospheric lifetime and stronger warming potential than carbon dioxide on a per unit basis, calculation of the global methane budget is increasingly important for identifying potential climate-change mitigation pathways, particularly in the short term. The GCP released a review draft of the Second Global Methane Budget (GMB) in July 2016, estimating that for the period 2000-2012, human activities accounted for about 60% of global methane emissions. Overall, uncertainties relating to emissions from natural sources—particularly wetlands and inland waters—were found to be higher than those from human sources. Improving methane observations at local-to-regional scales is one opportunity to reduce uncertainties in estimates of the total methane budget in the near future.



An accounting of global carbon dioxide sources and sinks, from 1870-2014. Carbon dioxide emissions from fossil fuels, industry, and land-use change are taken up by terrestrial ecosystems, the oceans, and the atmosphere. Increasing atmospheric carbon dioxide concentrations, in turn, are driving global warming. (Source: Global Carbon Project).

The GCB and GMB rely on observational data from many sources, with contributions from USGCRP agencies including NOAA, NASA, DOE, and NSF. USGCRP further contributes to the GCP through annual funding for the international programs that partner with the international research platform Future Earth. The U.S. Carbon Cycle Science Program Office, run through USGCRP, is an affiliated office of the GCP.

Highlight 7. Modeling Ice Sheets and Sea-Level Rise

Recent evidence has revealed that the Antarctic and Greenland ice sheets are not as static as once thought. Accelerated ice loss from the Greenland Ice Sheet, disintegrating ice shelves around Antarctica, and signs that several marine-terminating glaciers in Antarctica have begun an irreversible retreat all signal that changes are taking place faster than was thought possible. Ice sheets are projected to contribute significantly to global sea-level rise, which poses dramatic risks for coastal communities and island nations worldwide. In response to these rapid changes, several USGCRP agencies are funding efforts to improve representation of ice-sheet behavior in Earth System Models (ESMs), aiming to better estimate the potential future impacts of climate change on communities around the world.

International model intercomparison efforts such as the Marine Ice Sheet-Ocean Model Intercomparison Project, with participation from DOE, NASA, NOAA, and NSF, test and validate techniques to allow ice sheets and ice shelves to interact with other components of the Earth system. The newest generation of ESMs is making strides in allowing model ice sheets to respond dynamically to forcings from the ocean, atmosphere, and land components of the system and feeding those changes back into the climate system. Led by NASA, models like these are now gearing up for a head-to-head comparison in the context of the Ice Sheet Model Intercomparison Project, a component of the Coupled Model Intercomparison Project Phase 6 that has officially been sanctioned by the World Climate Research Programme.

Highlight 8. Improving Climate Predictability

As climate change increasingly impacts society and ecosystems, demand for reliable information about climate conditions now and in the future is growing. Climate research is conducted by two distinct communities, one working on climate forecasts for the near-term future and the other on climate-change projections over decades to centuries. Despite these different foci, the boundaries between these two communities increasingly overlap, and they share many common methods and challenges. Enhanced collaboration across modeling centers and communities can help create more valuable climate-information products for users at a broader range of timescales and higher spatial resolution.

With this goal in mind, USGCRP began convening an annual U.S. Climate Modeling Summit in 2015, bringing together institutional leaders from six leading climate model development centers and operational-climate-prediction centers in the United States. As recommended by the National Research Council, the 2016 Summit was dedicated to topical exchanges among centers with the goal of facilitating coordination on specific items of shared interest, including the upcoming 6th Coupled Model Intercomparison Project and other joint modeling activities, and opportunities and challenges for modeling with high resolution and advanced physical representation, which includes bridging timescales across weather and climate prediction and projection. Topics were discussed in the context of USGCRP research priorities, the evolving condition of Federal supercomputing and software, and interfaces with impacts and assessment models. Participants included representatives from NOAA's Earth System Models; NASA's Goddard Institute for Space Studies Model and Global Modeling Assimilation Office; the Community Earth System Model, which is hosted by the National Center for Atmospheric Research (NCAR) and funded by NSF and DOE; and the Accelerated Climate Model for Energy, funded by DOE with participation from eight national laboratories, NCAR, academic institutions, and the private sector.

Demand for reliable climate information at regional-to-local scales is also growing. To help address the common challenges both communities face in improving model resolution, DOE and NOAA jointly hosted a workshop on High-Resolution Coupling and Initialization to Improve Predictability and Predictions in Climate Models, September 30-October 2, 2015, with over 40 participants from both the prediction and projection communities. Participants summarized the current state of research surrounding high-resolution climate modeling, identified common challenges across communities, and proposed a collaborative research framework for quantifying the benefits of high-resolution coupled modeling for reducing model biases and for improving prediction skill on sub-seasonal to seasonal scales.

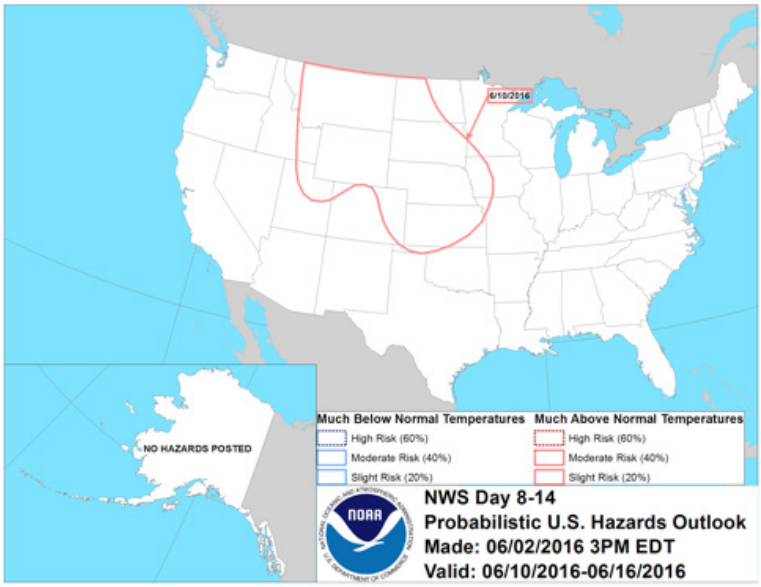
Informing Decisions

As the impacts of global change become more apparent, demand for information at all scales appropriate for decision making is growing. From community-level efforts to adapt to sea-level rise and reduce urban emissions to analyses of supply-chain risk from extreme weather to the national-security implications of climate-driven conflict abroad, Americans are making decisions to mitigate future climate change and adapt to its impacts now and in the future. USGCRP research creates the scientific foundation for providing timely, actionable information on global-change impacts and response strategies and for understanding how response measures impact the Earth system. USGCRP coordinates with producers and users of global-change science to understand the decisions users are facing, adjust research priorities, and ensure that decision-support tools meet user needs.

Multiagency expertise in extreme-heat prediction and harm reduction is supporting a new national information network designed to combat the rising burden of death and illness associated with extreme-heat events, involving local, regional, and international partners *(Highlight 9)*. An expanded regional drought early-warning system relies on interagency drought science and connections with regional, state, tribal, and private sector partners *(Highlight 10)*. USGCRP interagency models successfully predicted the strong El Niño event of 2015/2016, providing a critical early warning for decision makers in many sectors, including agriculture, water-resources management, and public health *(Highlight 11)*.

Decision-support efforts also include working with meteorological and rural development services to deliver climate forecast information to small farmers that dramatically reduced agricultural production losses during a severe drought *(Highlight 12)*, partnering to provide innovative data and information services to international decision makers responding to global change *(Highlight 13)*, and engaging Federal, state, and tribal partners in a coordinated response to adaptation needs for fish, wildlife, and plants *(Highlight 14)*.

USGCRP continues to work to integrate social-science methodologies to better understand global-change impacts on society, improve decision support, and evaluate response options. Interagency efforts have provided guidance for incorporating social sciences into scientific assessment products, including methods for measuring societal impacts of climate change *(Highlight 15)*.



NOAA's U.S. Temperature Hazards Outlook, available on the National Integrated Heat Health Information System web portal, provides a probabilistic estimate of where temperatures are expected to be either much below normal (15th percentile) or much above normal (85th percentile), and where those conditions pose a hazard to life or property. Forecast confidence is categorized as slight, moderate, or high, with the categories indicating a 20%, 40%, or 60% chance of occurrence, respectively. Forecasts are available for 3-7 days or 8-14 days in the future; this image depicts a 8-14 day forecast. Short-range forecasts and region-specific information are available through local National Weather Service Forecast Offices. (Source: NOAA).

Highlight 9. Reducing the Health Risks of Extreme Heat

Awareness surrounding the connection between climate change and human health is growing. USGCRP's The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment projected a potential increase of "thousands to tens of thousands of premature heat-related deaths in the summer" by 2100, driven by longer, more frequent, and more intense heat waves.

The National Integrated Heat Health Information System (NIHHIS), launched by NOAA and the Centers for Disease Control and Prevention (CDC) in June of 2015, has made significant progress towards linking early-warning capabilities to improve preparedness for extreme-heat events. Building on the October 2014 Heat Health Summit, a July 2015 planning workshop focused on developing NIHHIS and understanding local and international approaches to heat-health early warning and long-term risk reduction. These workshops catalyzed a global wave of interest in improving the heat-health information available to decision makers, as well as institutional capacity to build preparedness, communication, and knowledge sharing across disciplines and geographies. During the Federal Emergency Management Agency (FEMA) PrepareAthon! Extreme Heat Week in May of 2016, a White House webinar on preparing communities for extreme heat was held to share knowledge and build capacity for addressing heat risks, and the NIHHIS web portal was launched with multiagency support—including EPA, DOD, NOAA, FEMA, the Occupational Safety and Health Administration, the National Institutes of Health, the Centers for Disease Control and Prevention (CDC), and others.

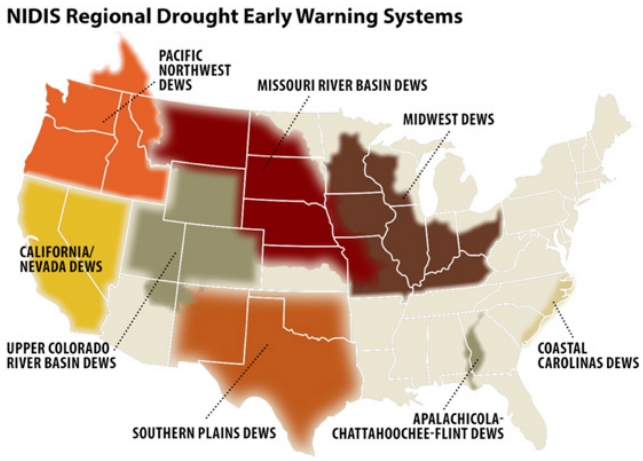
NOAA-supported research on prediction of extreme heat from weather-to-climate timescales continued while CDC pursued a comprehensive national assessment of health risks associated with extreme heat. Local NIHHIS engagements in the Southwest and Northeast, based in El Paso, Texas and New York, New York, respectively, are developing a thorough understanding of the local experience of extreme heat, as well as research and integrated climate-health-information needs. Additional local-regional engagements are planned for 2017 and onward in the West, Midwest, and Southeastern United States. At the international scale, partnerships have expanded with government agencies and nongovernmental actors, including the India Meteorological Department and the Natural Resources Defense Council. NIHHIS was visible at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change in Paris in December 2015, and the South Asian Climate Outlook Forum in April 2016.

Highlight 10. Building Regional Collaboration for Drought Resilience

In 2015, drought impacts in the Western United States cost an estimated $4.5 billion[16]. Impacts included the fallowing of hundreds of thousands of acres of farmland, excess groundwater pumping, and the exacerbation of wildfire conditions, which contributed to fires that caused the highest annual total of U.S. acreage burned since record-keeping began in 1960. As these impacts become more prevalent under a changing climate, preparedness, including an early-warning system for drought conditions, is increasingly important in many parts of the United States. The National Integrated Drought Information System (NIDIS) has an interagency mandate to create a nationwide Drought Early Warning System (DEWS) by integrating and coordinating efforts to research, monitor, predict, prepare for, and mitigate drought conditions. The goal of the DEWS is to make climate and drought science easily understandable, usable, and readily available to decision makers and improve the capacity of stakeholders to cope with the impacts of drought.

NIDIS has taken a regional approach to building a national system. Since 2007, NIDIS and its interagency partners have established regional DEWS in the Upper Colorado River Basin, Southern Plains states, the Apalachicola-Chattahoochee-Flint River Basin states, the Missouri River Basin, the coastal Carolinas, and California/Nevada. In February 2016, NIDIS and its partners launched new regional DEWS in the Pacific Northwest and the Midwest.

NIDIS works together with representatives and agencies of the USDA, EPA, Bureau of Reclamation, NASA, DOE, Army Corps of Engineers, USGS, FEMA, NOAA, state natural resource and water departments, state climatologists, tribal representatives, and stakeholders from the private sector. In addition, the National Drought Resilience Partnership, a group of seven Federal agencies spearheaded by USDA and NOAA, was established to enhance access to Federal drought resources to help communities better prepare for drought and reduce its impacts on families and businesses.



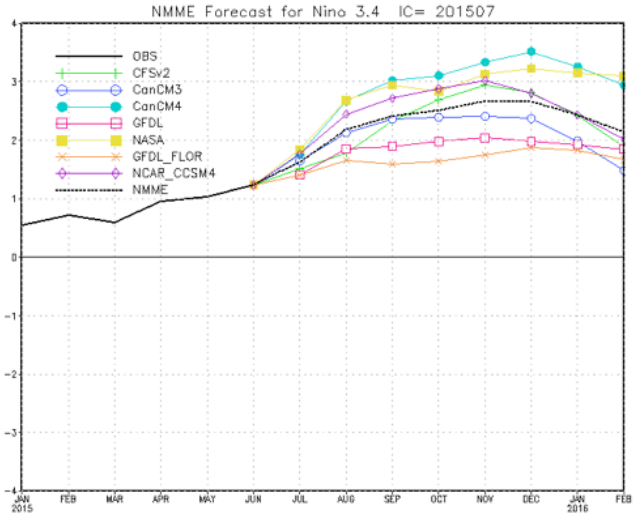
Map of regions with National Integrated Drought Information System (NIDIS) Regional Drought Early Warning Systems (DEWS) currently underway. DEWS coordinate and provide climate and drought science, monitoring, and forecast products; identify user needs for information and resources; and help build stakeholder capacity to cope with the impacts of drought. (Source: NIDIS).

Highlight 11. Successfully Predicting the Large 2015/2016 El Niño

The El Niño/Southern Oscillation (ENSO) phenomenon is a periodic fluctuation of sea-surface temperatures and atmospheric pressure across the tropical Pacific Ocean. During the El Niño phase of the cycle, the eastern tropical Pacific Ocean warms substantially. This can cause significant short-term increases in global-average surface temperatures, and through atmospheric teleconnections, a strong El Niño event can affect weather patterns around the globe. A particularly strong El Niño emerged during the winter/spring season of 2015/2016,

rivaling the major El Niño of 1998. Using a state-of-the-art seasonal forecasting and research tool, USGCRP agencies successfully forecasted the event six months before it occurred, providing advance warning of potentially disruptive shifts in weather and climate patterns.

Based on models from NOAA, DOE, NSF, NASA, and other modeling centers, the North American Multi-Model Ensemble (NMME) produces skillful short-term (intra-seasonal to interannual) climate forecasts on a routine basis. El Niño forecasting aids decision makers in many different industries, including agriculture, water-resources management, public health, emergency management, and national security, who stand to benefit from more accurate forecasts of climate extremes. NMME seasonal forecasts are disseminated via NOAA's National Weather Service and U.S. Drought Outlook.



Forecast of the NINO3.4 index made by members of the North American Multi-Model Ensemble in June 2015. Individual model forecasts are indicated by colored lines; the ensemble average is the black dotted line. The NINO3.4 index is the sea-surface temperature anomaly (departure from average) in degrees centigrade (C), averaged across the region between +/- 5 degrees latitude and 170W to 120W longitude. An El Niño event is typically defined as the NINO3.4 index exceeding 0.4 C for a period of six months or more. (Source: NOAA).

Highlight 12. Providing Drought Information to Farmers

Since 2014, Jamaica has experienced one of its worst droughts in a decade, and the fourth worst on record since the 1970s. The drought has profoundly affected the agricultural sector: agricultural production fell by roughly 50% between 2013 and 2014. In response, Jamaica's Rural Agricultural Development Authority (RADA) and the Jamaican Meteorological Service (JMS), in collaboration with the International Research Institute for Climate and Society (IRI) and with support from USAID and NOAA, produced new seasonal drought-related forecast information for farmers. Combining information from the Standardized Precipitation Index and IRI's Climate Predictability Tool, the tool forecasted con-

Jamaican farmers discuss the drought outlook with agricultural-extension agents. When shared with farmers effectively, seasonal drought-related forecast information has been shown to significantly cut agricultural-production losses under drought conditions. (Source: Zack Guido).

ditions up to three months into the future.

Forecast information was then provided to hundreds of farmers across Jamaica by JMS and RADA during June 2014-June 2015, via farmer forums, text messages, extension agents, and direct contact with JMS. In doing so, JMS and RADA tested an innovative model for providing climate-information services to farmers, with potential for generating new insights relevant to delivering climate-information services for agriculture in different contexts.

In 2015, USAID and NOAA supported an economic-impact evaluation study by researchers from the University of Arizona of the information service[17]. The study documents that agricultural-production losses of the farmers who received the information service were significantly smaller. More specifically, some farmers were able to prevent agricultural-production losses by up to 40%. This can be attributed to the coping strategies adopted by farmers in light of the information service: they adjusted planting and sowing time, choice of crops, harvesting time, amount of land cultivated, mulching practices, chemical and fertilizer use, and irrigation.

Highlight 13. Implementing Data Services for Development

An example of the web-based information products available through the Agricultural Atlas of Nepal, created under the SERVIR-Himalaya initiative supported by USAID and NOAA. (Source: ICIMOD).

SERVIR—meaning "to serve" in Spanish—combines NASA's Earth-observations data and tools with USAID's expertise in international development, supporting the use of geospatial technologies to help decision makers in developing countries respond to environmental change. Through the SERVIR network, experts at regional hubs in Eastern and Southern Africa, Hindu Kush-Himalaya, and the Mekong River Basin partner with local decision makers and U.S.-based scientists to create new datasets, maps, and decision-support tools related to climate adaptation and mitigation, disaster-risk reduction, water and natural- resource management, land-use planning, and infrastructure development. SERVIR hubs also provide training to build capacity in local institutions for accessing and using scientific data and tools for decision making.

The SERVIR website offers access to a range of environmental information, maps, satellite and sensor data, and other analysis tools. In countries such as Nepal, where a large percentage of the population depends on rainfed agriculture for subsistence, climate-related risks to crop production pose serious challenges to food security and economic stability. To help address this critical issue, SERVIR-Himalaya and its partner organization the International Centre for Integrated Mountain Development (ICIMOD) worked with the Nepal Ministry of Agricultural Development (MoAD) to create the first-ever web-based Agricultural Atlas of Nepal. The Atlas, which provides free access to information on crops and livestock products to a wide audience, is one component of an Agriculture Management Information System that serves as a basis for agricultural and food-security analysis and planning in Nepal. MoAD and ICIMOD are also developing an agricultural-monitoring system

based on satellite data to provide key agricultural information on crop growth and stress as well as early signs of drought, enabling officials to plan for and mitigate the effects.

Highlight 14. Protecting Fish, Wildlife, Plants, and Ecosystems in a Changing Climate

As climate change and other stressors increasingly threaten ecosystem health, natural-resource agencies and their partners and stakeholders are wrestling with similar management challenges and seeking common, coordinated solutions. Called for by both Congress and the Executive Branch, the National Fish, Wildlife, and Plants Climate Adaptation Strategy (NFWPCAS or Strategy) was developed collectively by diverse teams of experts from Federal, state, and tribal conservation agencies and through an extensive national dialogue.

The Pacific walrus in Alaska is threatened by reductions in the thickness and extent of sea ice driven by climate change. The National Fish, Wildlife, and Plants Climate Adaptation Strategy aims to protect species like the Pacific walrus under pressure in a changing climate. (Source: U.S. Fish and Wildlife Service).

The Strategy identifies seven goals for helping fish, wildlife, plants, and ecosystems cope with the impacts of climate change and identifies the scientific and technical capacity needed to implement them. Since its release in 2013, Federal, state, and tribal agencies have worked together through a Joint Implementation Working Group (JIWG) to promote the Strategy as a resource for adaptation planning at national to local levels and to support partners in implementing recommended strategies and actions.

In 2016, the partnership launched the first national Climate Adaptation Leadership Award for Natural Resources to recognize exemplary efforts by Federal, state, tribal, local, and non-governmental individuals and entities to help safeguard America's living natural resources from climate change. The first-ever award recipients were chosen from among 47 diverse nominees from Federal, state, tribal, local, and non-governmental organizations. The JIWG is also assisting in the coordination of the Resilient Lands and Waters Initiative, a focused Federal effort by NOAA, DOI, EPA, and the U.S. Army Corps of Engineers that builds on existing collaborative landscape-conservation partnerships to help ensure that long-term conservation efforts take climate change into account.

There are many examples of efforts across the United States that have been informed by the Strategy and the JIWG. The state of California is working with partners to develop a reintroduction plan for winter-run Chinook salmon that will support a more resilient population in the face of climate change. NOAA Fisheries has released a climate-change science strategy to increase the production, delivery, and use of climate-related information to fulfill agency mandates. An interagency collaboration, led by the Bureau of Land Management, is developing a National Seed Strategy to ensure the availability of appropriate seeds in a changing climate. The Swinomish Indian Tribal Community is modeling future conditions to estimate the impacts from sea-level

rise and storm surge on the near-shore environment of their reservation. Finally, the U.S. Fish and Wildlife Service (FWS) is working to incorporate climate-change considerations into a variety of areas including refuge planning, land acquisition, and financial assistance.

Going forward, the continued success of this effort relies on sustained action and engagement by Federal, state, local, and tribal governments, and many partners at all levels. This effort is led by the FWS, NOAA, the California Department of Fish and Wildlife (on behalf of states more broadly), and the Great Lakes Indian Fish and Wildlife Commission.

Highlight 15. Increasing Representation of the Social Sciences in Global Change Research

USGCRP's 2012-2021 Strategic Plan recognized the need for better representation of the social dimensions of global change within the Program's activities, in order to fulfill its goals of advancing fundamental global-change science while informing decisions and engaging stakeholders. Under this impetus, the interagency Social Science Coordinating Committee (SSCC) was established in 2014 and has made progress in developing strategies for integrating the methods, findings, and disciplinary perspectives of the social and behavioral sciences into USGCRP's activities.

Since its inception, the SSCC has engaged with the USGCRP National Coordination Office, various USGCRP interagency working groups, and scientists outside of USGCRP agencies and the government to better incorporate social-science considerations into USGCRP programs and activities. Most significantly, the SSCC reviewed the 2014 National Climate Assessment (NCA) to identify ways authors can better incorporate social sciences in future NCAs and other assessment products to enhance climate research and its communication and the relevance of the NCA to decision makers. Considerations range from the structuring of future reports, to new topics (e.g., scenario analysis and economic valuation of climate-change impacts), to best practices for integrating social-science methodologies and expertise and the human dimensions of climate change into the NCA. The SSCC also reviewed the USGCRP indicators system *(Highlight 17)* and developed recommendations for the inclusion of societal indicators of climate-change impacts, vulnerability, and adaptive capacity. In addition, planning for a workshop with several social-science professional associations is underway. The workshop will identify specific actions that USGCRP and its member agencies could take to enhance the effectiveness of Federal climate-change research activities.

Conducting Sustained Assessments

Scientific assessments provide a snapshot of current scientific understanding on a topic, synthesizing large amounts of research to help scientists and decision makers anticipate change, evaluate information available for decision support, and identify knowledge gaps and needs. With a rapidly evolving, policy-relevant issue such as climate change, frequent assessments are key inputs for decision making. USGCRP is mandated by the GCRA to conduct a quadrennial National Climate Assessment (NCA) on the impacts of climate change in the United States, and to coordinate Federal participation in relevant international assessments, such as those led by the Intergovernmental Panel on Climate Change (IPCC). Under the 2012-2021 Strategic Plan, USGCRP

began the transition to a sustained-assessment process to provide timely information to decision makers on an ongoing basis and to enable more efficient and effective production of quadrennial reports.

Sustained assessment capacity directly connects research with decision making, providing a mechanism for regularly evaluating the state of knowledge while engaging with stakeholders to ensure that emerging tools and capabilities meet their needs[18]. Special reports on key topics allow new syntheses and insights to be released as they emerge, and provide substantive technical inputs to the NCA. In April 2016, USGCRP released a major assessment of the impacts of climate change on human health in the United States, led by EPA, NOAA, and HHS, that broke new ground in quantifying projected health impacts and identifying vulnerable populations *(Highlight 15)*. As a contribution to the NCA, a 2015 USDA-led assessment addressed climate change-related disruptions to the U.S. food system and global food security, and a 2016 USDA-Forest Service-led assessment provided a scientific basis for drought management on forests and rangelands. Interagency reports to update the state of knowledge on climate science and the carbon cycle are also underway.

Agencies are investing in research, tools and products to support a sustained assessment capacity, relying on interagency investments in observational systems and modeling capabilities to document, understand, and communicate change. USGCRP is supporting pilot testing of a climate-indicators platform that can clearly convey key climate-change impacts to decision makers *(Highlight 16)*. A number of USGCRP agencies are collaborating to develop and refine scenarios of changing climate, population, and land-use/land-cover dynamics that can inform ongoing assessment activities and decision-support tools *(Highlight 17)*. USGCRP's Global Change Information System provides traceability for datasets, figures, and publications used in all of these efforts *(Highlight 18)*.

At the international level, USGCRP serves as a locus of U.S. activity in support of the IPCC, including its periodic Assessment Reports as well as its occasional topic-focused special reports. The USGCRP agencies support most of the authors, observations, and model projections that the United States contributes to these reports. Through their support of researchers, observations, and model projections, USGCRP agencies similarly contribute to a number of ongoing international assessments, including the quadrennial ozone assessment of the World Meteorological Organization and United Nations Environment Programme, the United Nations World Ocean Assessment, and assessments conducted by the Arctic Monitoring and Assessment Program.

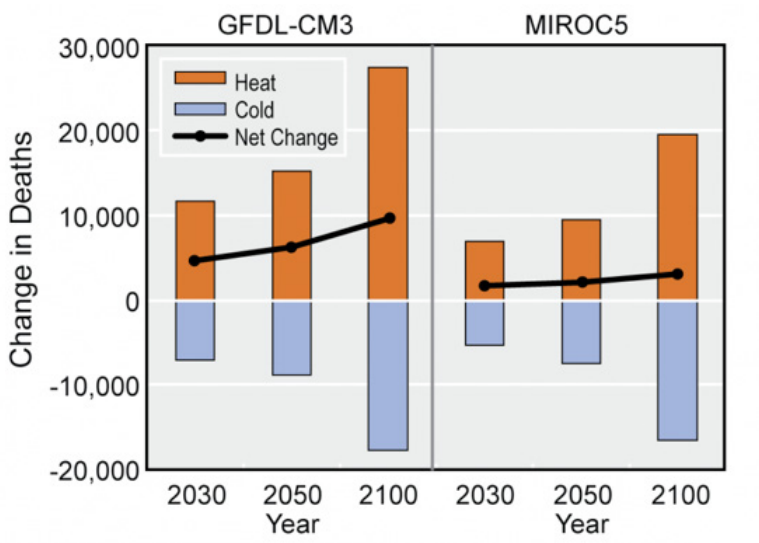
The sustained-assessment process is a key avenue of engagement with USGCRP's stakeholders. Recognizing the value of a wide range of expertise and experience in fulfilling its goals, USGCRP has built engagement into the sustained-assessment process at multiple levels, including program planning, implementation, and evaluation and has convened a Federal Advisory Committee to advise the Program on all aspects of the sustained-assessment process, including its engagement efforts *(Highlight 19)*.

Highlight 16. Analyzing the Rising Costs of Climate Change to Human Health

In April 2016, USGCRP released The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment (Climate and Health Assessment), a significant advancement in understanding of the impacts of climate change on human health. It strengthens the finding in previous literature that climate change increases health risks for all Americans, that certain populations are particularly vulnerable, and that these threats are likely to increase as climate change progresses[19]. In particular, an annual increase of

thousands to tens of thousands of premature heat-related deaths in the summer, and a smaller decrease of premature cold-related deaths in the winter, are projected each year as a result of climate change by the end of the century. Other topics covered include weather and climate extremes, air quality, vector-borne disease, water- and food-related issues, and mental health and well-being.

The Climate and Health Assessment is the product of more than 100 experts and eight Federal agencies and represents a major effort of the sustained National Climate Assessment process. The report was informed by input gathered in listening sessions, scientific and technical information contributed through open solicitations, and peer-reviewed literature. It underwent rigorous reviews by the public and by scientific experts inside and outside of the government, including a special committee of the National Academies of Sciences, Engineering, and Medicine. The three-year development was overseen by the USGCRP-coordinated Interagency Working Group on Climate Change and Human Health and was led by EPA, HHS, and NOAA.



This figure depicts the projected increase in deaths due to warming in the summer months (hot season, April–September), the projected decrease in deaths due to warming in the winter months (cold season, October–March), and the projected net change in deaths compared to a 1990 baseline period for 209 U.S. cities, using the GFDL–CM3 and MIROC5 climate models. Both models project a net increase in deaths. (Source: USGCRP, adapted from Schwartz et al. 2015).

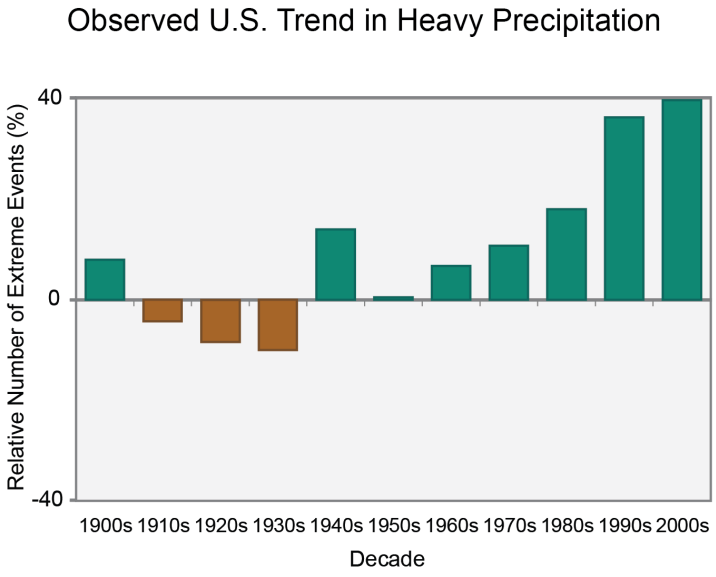
A companion website, health2016.globalchange.gov, was released with the report. It allows users to explore and share the content of the report from desktop, tablet, and mobile devices and received over 36,000 visits in its first month. Integration with USGCRP's Global Change Information System provides connection and discoverability of the 60 figures, 29 findings, and over 1,500 references contained in the report *(Highlight 18)*. The Climate and Health Assessment products offer a wealth of data and knowledge to support decision making, ensuring that the information provided is accessible and readable by a wide audience.

Highlight 17. Improving Indicators of Change

Indicators are measurements or calculations that represent how a complex system is changing over time—for instance, the unemployment rate is an indicator of overall economic health. For the climate system, indicators offer a simple representation of how a highly complex system is changing, providing a benchmark for decision makers that can be used as a gateway into more complex and context-specific information. Indicators allow multiple audiences—including scientists, planners, policy makers, educators, and the public—to better understand and communicate the causes and effects of climate change. USGCRP has developed a pilot set of climate indicators to communicate some of the key aspects of a changing climate, including temperatures over land and at sea, greenhouse-gas levels in the atmosphere, observed trends in heavy precipitation, and related effects in sectors such as public health and agriculture.

This pilot indicators platform is the first step in developing a more comprehensive interagency indicators system that can support the sustained National Climate Assessment. Agency contributions to the indicators effort include 25 new NASA-funded three-year projects to support the development of a broader suite of climate indicators. Projects include potential indicators related to extratropical cyclone activity, vegetation water stress, extreme precipitation, and agricultural productivity. EPA continues to update its suite of climate-change indicators, and published a new report in summer 2016. EPA indicators updated with 2015 data include drought, extreme temperature, heat-related deaths, U.S. and global sea level, wildfires, and ragweed- pollen season. NOAA continues to provide funding, technical support, and data services for the interagency indicators system. These indicators draw from multidisciplinary observational capabilities that provide the ability to monitor and understand change over time *(Appendix III. Observations to Support Global-Change Research)*.

USGCRP is also testing ways to connect indicators to other agency products, information, and resources that can help people make decisions.



One measure of a heavy precipitation event is a two-day precipitation total that is exceeded on average only once in a five-year period, also known as a once-in-five-year event. As this extreme precipitation index for 1901-2012 shows, the occurrence of such events has become much more common in recent decades. Changes are compared to the period 1901-1960, and do not include Alaska or Hawai'i. The 2000s decade (far right bar) includes 2001-2012. (Source: USGCRP, adapted from Kunkel et al. 2013[20]).

Highlight 18. Developing Scenarios of Change

Scenarios are plausible alternative futures, each describing what might happen under a range of possible assumptions about policy decisions and the behavior of the Earth system. By illustrating possible future conditions, scenarios provide a basis for analyzing the potential impacts of and responses to global change. USGCRP is working to develop scenarios of change for the United States that can feed into the sustained-assessment process and support the needs of both scientists and stakeholders, focused on population, demographics, land-use change, sea-level rise and coastal flood risk, and climate change.

Population, demographics, and land-use change: Changes in future population and land use have the potential to affect—and be affected by—climate change. In 2015, USGCRP convened two workshops on developing demographic and land-use scenarios for the United States. Modelers and scenario users convened to identify critical uncertainties in projections; key natural, socioeconomic, and policy variables to consider; and capabilities (or gaps therein) to produce long-term projections for future research and decision-support needs. USGCRP is coordinating the development of U.S. population scenarios using Integrated Climate and Land-Use Scenarios (ICLUS), a suite of models representing demography, migration, and spatial allocation of

housing that are consistent with the Shared Socioeconomic Pathways, a set of possible development pathways used by the climate-change-research community to standardize analyses. The use of ICLUS v2 allows the exploration of a range of development pathways, improving the ability to understand climate-change impacts, vulnerability, and mitigation and adaptation options.

Sea-level rise: In 2015, at the request of the White House Council on Climate Preparedness and Resilience, USGCRP and the National Ocean Council convened an interagency task force to develop consistent, accessible, authoritative, and regionally-appropriate scenarios of future sea-level rise and coastal-flood hazard for the United States, and to integrate these scenarios into existing Federal tools and capabilities for supporting preparedness planning. These scenarios are intended to serve as a starting point for coastal preparedness planning and risk-management processes and provide a basis for assessing societal and ecological risks associated with sea-level rise in the Fourth National Climate Assessment (NCA4). The task force is developing regional-scale scenarios for the entire U.S. coastline based on the global scenarios developed for the Third National Climate Assessment (NCA3), accounting for key determinants of local variability in sea-level rise. The task force is also developing scenarios of extreme-water levels associated with these sea-level rise scenarios. Participating agencies are working to integrate these scenarios with existing tools and approaches useful to communities and stakeholders, such as floodplain mapping and visualization, flood-elevation engineering tools, and tools for estimating the future extent of coastal erosion. Participating agencies include USGS, U.S. Army Corps of Engineers, FEMA, NOAA, EPA, and NASA.

Climate change: In May 2015, USGCRP released a memo entitled "U.S. Global Change Research Program General Decisions Regarding Climate-Related Scenarios for Framing NCA4", signaling to the climate change and impacts scientific communities that NCA4 would base its climate scenario development on the IPCC Representative Concentration Pathways and Coupled Model Intercomparison Project Phase 5 ensemble of model runs. Subsequently, USGCRP is developing and implementing an overall strategy for developing authoritative, relevant, and accessible climate-change scenarios for NCA4 and the Sustained Assessment. Participating agencies include NASA, NOAA, DOE, the Bureau of Reclamation, USGS, U.S. Army Corps of Engineers, EPA, and the Office of Science and Technology Policy.

These efforts are focused on the development of scenario products, and accompanying guidance, for NCA4 author teams and for Federal, state, tribal, and local users in need of scenarios to support their planning and decision making. Scenarios are based on aspects of the U.S. climate most relevant for assessing key societal risks, such as changes in the frequency and intensity of weather and climate extremes, and attempt to characterize these risk-relevant climate changes in the face of current scientific uncertainties.

Highlight 19. Expanding the Global Change Information System

The Global Change Information System (GCIS) was launched in May 2014 as a repository of global-change data that could be easily and efficiently accessed, integrated with other data sets, and maintained and expanded over time. GCIS initially supported traceable data and metadata for findings and graphics in the Third National Climate Assessment (NCA3) and expanded considerably in support of the 2016 assessment The Impacts of Climate Change on Human Health in the United States *(Highlight 15)*.

From the 2014 release of NCA3 to September 2016, the number of authors catalogued in GCIS (which include

report authors as well as those contributing to input references) expanded from 1,141 to 9,500, and the number of datasets from 23 to 3,133. These inter-linked resources provide traceability and transparency of Federal global-change assessments, tools, and data, allowing users to discover authors and organizations who produced a figure within a report, trace the datasets used to produce the figure, and learn about who produced the data. In addition to providing traceability of global-change assessments and tools, efforts are underway to demonstrate how the GCIS can support the charge of the President's Climate Action Plan by facilitating an integration of the Climate Data Initiative with other Federal initiatives.

GCIS Resources	May 2014	September 2016
Authors	1,141	9,500
Books	166	199
Datasets	23	3,133
Figures	490	680
Instruments	0	530
Journal Articles	2,086	3,368
Journals	536	841
Organizations	845	5,268
Platforms	0	282
Reports	704	1,060

USGCRP's Global Change Information System (GCIS) has expanded significantly since its initial support of the Third National Climate Assessment (2014). GCIS provides traceability and transparency of Federal global-change assessments, tools, and data. (Source: USGCRP).

Highlight 20. Expanding Engagement with USGCRP

Recognizing the value of a wide range of expertise and experience in building its decision-support capacity, USGCRP has built engagement into the sustained-assessment process at multiple levels. Public comment periods, town-hall events, and calls for technical contributions encourage input from state, local, and tribal governments; academic institutions; the private sector; and the interested public. NCAnet, a network of organizations involved in the National Climate Assessment (NCA) and its communication, has grown to include more than 180 organizations and played an important role in the release of the interagency assessment report The Impacts of Climate Change on Human Health in the United States *(Highlight 15)*. Supporting groups such as Resilience AmeriCorps and Climate Action Champions help connect USGCRP science with practitioners making adaptation and mitigation choices. The information exchanged through these interactions is helping USGCRP develop more relevant and more useful scientific products.

A better understanding of the needs of USGCRP stakeholders helps ensure that the scientific products USGCRP provides are clear, topical, and applicable to the specific needs of users at multiple levels. As USGRCP looks ahead, the information gained from engagement activities will help shape the future of the Program. NOAA, on USGCRP's behalf, has convened a 15-member Federal Advisory Committee (FAC) to advise the sustained-assessment process on enhancing engagement with stakeholders, assessment activities, and the quadrennial NCA report. FAC members are strategic thought leaders with expertise in science, communications, engagement, and education, and will advise USGCRP on how to make the sustained-assessment process and products more useful to USGCRP stakeholders, as well as to connect the Program to new groups that would not be reached otherwise.

Communicating and Educating

An engaged, well-informed public and an appropriately-trained workforce are key components of building a national response to global change. As the coordinating body for Federal global-change research, USGCRP is in a unique position to deliver credible communication, education, and capacity-building products and programs that integrate across a diverse knowledge base. USGCRP promotes public understanding of global-change science through the development and dissemination of educational products, coordination of multi-agency initiatives, and support for training to develop the scientific workforce of the future.

An interagency initiative on climate education and literacy is putting tools and information on climate risks and solutions, including climate-based learning activities, into the hands of educators, students, and the public *(Highlights 21–22)*. Consistent with the GCRA directive to promote international cooperation on global-change research, and involve scientists and policymakers from developing nations in these activities, other initiatives include international outreach on public health and through training of young scientists in global-change research and adaptation *(Highlight 23)*, and capacity-building in India to increase resilience of the public-health sector to climate risk *(Highlight 24)*.

Highlight 21. Implementing the Climate Education and Literacy Initiative

The Climate Education and Literacy Initiative, launched by the White House Office of Science and Technology Policy in coordination with USGCRP and many of its member agencies, helps connect American students and citizens with the best available, science-based information about climate change. Efforts through the Initiative are increasing learning opportunities for students, equipping educators with science-based information and resources, enhancing climate-related professional development and training, and engaging citizens through informal climate education where they work and play.

The "Our Time to Lead: Youth Engagement in Climate Change" event at COP21 on November 30, 2015. As part of the Climate Education and Literacy Initiative, the event engaged young leaders from around the world. (Source: Frank Niepold, NOAA).

As commitments in support of the Initiative, a group of Federal and non-Federal collaborators formed the #Youth4Climate coalition in advance of the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change in Paris, December 2015. Participants included NOAA, DOE, Connect4Climate, the Association of Science-Technology Centers (ASTC), the Climate Literacy and Energy Awareness Network, the Wild Center, Climate Generation: A Will Steger Legacy, Alliance for Climate Education, Earth Day Network, Climate Interactive, and other organizations. The program at COP21 included the U.S. Center-hosted "Our Time to Lead: Youth Engagement on Climate Change," an ASTC, Universcience, and NOAA interactive video conference to engage young leaders from around the world. Many students and educators from the United States and around the world were at events in Paris, amplifying the need for progress back

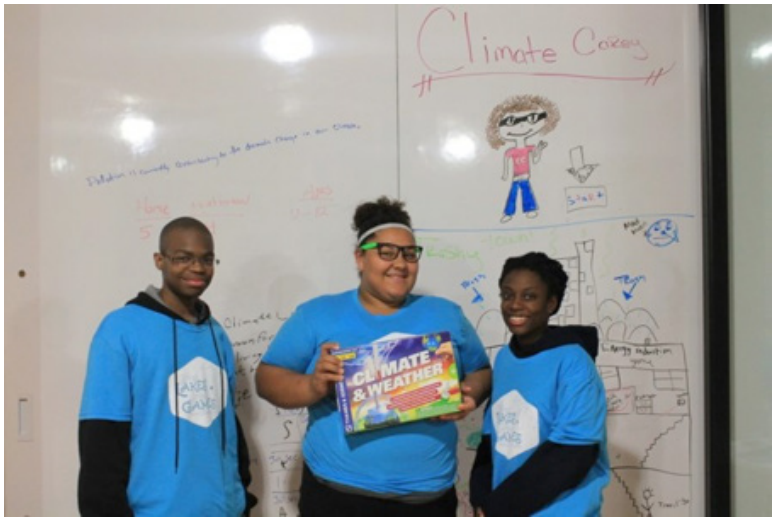
home and participating through social media, using the hashtags #Youth4Climate and #COP21 to bring their knowledge and enthusiasm to the climate discussions.

Participants in the Initiative have so far included hundreds of educators, thousands of students, and millions of engaged citizens. These leaders have reached tens of thousands directly through their work and countless more through social media and by delivering quality educational resources online and through other channels.

Highlight 22. Using Games for Climate Education

As a part of the White House Office of Science and Technology Policy's Climate Education and Literacy Initiative *(Highlight 21)*, Federal and non-governmental experts are collaborating to harness the promise of educational games and interactive media to enhance understanding and awareness of climate-change impacts and solutions. Games are increasingly used in educational settings to help inspire curiosity, creativity, collaboration, optimism, and problem-solving skills among a wide variety of audiences. Games address real-world challenges, compress time and space, encourage systems thinking, and promote active engagement, making them particularly well-suited to climate-change education.

Two "game jams" in the past year have helped to connect American students and citizens with the best-available science-based information about climate change. In October 2015, the Climate Game Jam—held simultaneously at 11 sites across the United States—resulted in 30 new game prototypes that allow players of all ages to learn about climate change and resilience through analog and digital games. In April 2016, the Climate Game Jam Water invited teams of students in grades K-16 at nine sites to modify existing games and create new games that explored topics such as changing precipitation patterns, freshwater supply, ocean acidification, polar issues, water use, and marine and freshwater ecosystems. Selected winners from both game jams were invited to showcase their creations during special events at the Smithsonian National Museum of Natural History.



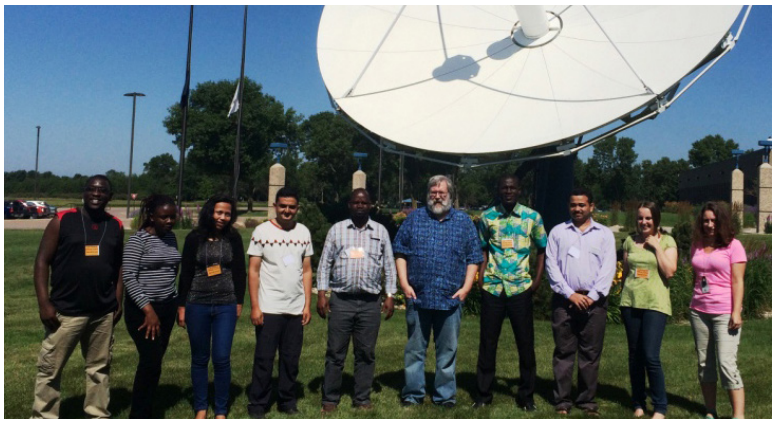
Participants at the Climate Game Jam. (Source: Frank Niepold, NOAA).

Highlight 23. Advancing Knowledge on Global Environmental Change in Africa and Asia-Pacific

START (global change SysTem for Analysis, Research and Training) promotes research-driven capacity-building to advance knowledge on global environmental change in Africa and Asia-Pacific, through research grants and fellowships, knowledge assessments and syntheses, curricula development, advanced-training institutes, multi-stakeholder dialogues, and place-based strategic planning. In 2015, with support from USGCRP, START

enhanced the ability of over 300 researchers selected as fellows and their partners to incorporate climate information into decision making and strengthened the capacities of over 250 partner institutions to more effectively address climate-change concerns related to disaster- risk reduction, adaptation, and Earth observations. To jumpstart their work in global-change research and adaptation, fellows received training and mentoring at host institutions. START also awarded nearly 30 follow-on grants to scientists and practitioners to extend their START learning experience at their home institutions.

START is an implementation partner of the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) program, a global collaborative effort that includes NASA, USGS, Boston University, the University of Maryland, and Wageningen University in the Netherlands. This program is helping to strengthen skills of developing country scientists to access and use Earth-observation data and build networks for knowledge sharing on land-use/land-cover change. In 2015, the GOFC-GOLD project supported four regional network-building efforts in Asia, Africa, Eastern Europe, and Latin America; facilitated a Data Initiative advanced training event that enabled young developing country scientists to gain key skills in data management, analysis, and relevant software; and contributed to relevant Group on Earth Observations/ Global Earth Observation System of Systems activities.



Fellows representing nine countries attend a 2015 GOFC-GOLD Data Initiative Advanced Training in South Dakota. (Source: START).

Highlight 24. Building Public-Health Capacity for Adaptation in India

Like many developing countries, India faces a disproportionate share of adverse impacts from climate change, including the exacerbation of its already substantial public-health challenges. The government of India has recognized health as a priority area in its climate-adaptation strategy, and many states now include initiatives related to health in their climate action plans; however, internal public-health capacity for climate-change adaptation is limited. The National Institutes of Health, with support from NOAA and the Department of State, collaborated with organizers in India to host a three-day training workshop in 2015 for public-health researchers and professionals on the health impacts of climate change. This activity supports the U.S.-India Partnership for Climate Resilience, launched by President Obama and Prime Minister Modi in 2014 to catalyze inter-sectoral action on climate resilience. Health is a critical sector for adaptation and has been recognized as such in the adaptation assessments and plans published by both countries.

The workshop was a first step in developing a network, or community of practice, focused on the core topics of vulnerability, adaptation, and health co-benefits of efforts to reduce climate change. The organizers invited early-career faculty, researchers, and others in the hope of expanding the number of experts who can assist in the country's adaptation efforts. The importance of community-based participatory research, and in particular, the need to engage community stakeholders in research design and project implementation, was a key focus.

The meeting brought together a range of stakeholders from India, including the Ministries of Health and Environment, Forestry and Climate Change, Indian Meteorological Department, National Institute of Urban Affairs, National Health Systems Resource Center, Indian Institute of Public Health, and All India Institute of Medical Research.

Looking ahead, the network's goal is to help India build resilience in its health sector, particularly through rigorous adaptation planning at the subnational level. Planned activities include holding additional training events, facilitating local research, and assisting with the development of early-warning systems and health-related action plans. Through both domestic and U.S.-India collaborations, the organizers hope that the community of practice will play a central role in building India's capacity to address the health impacts of climate change.